CHAPTER 12

MICROWAVE ANTENNAS

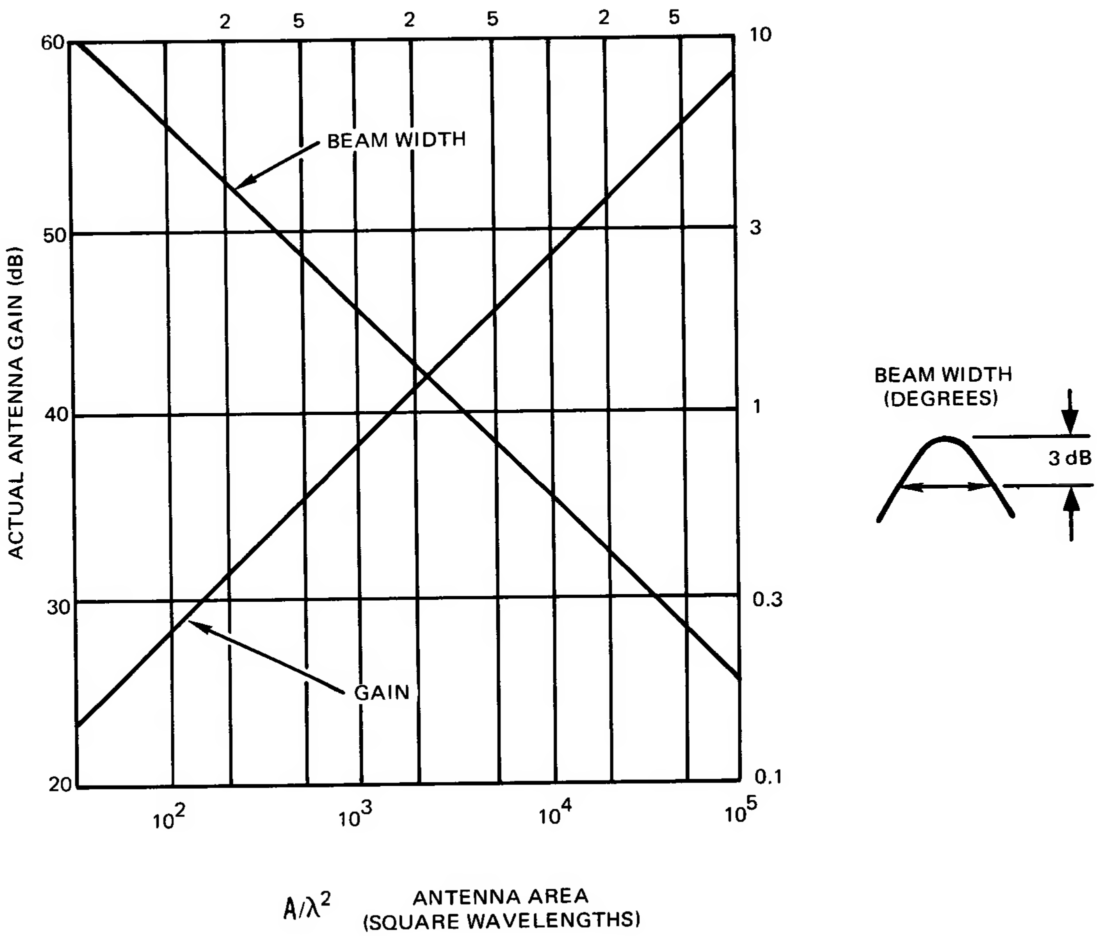
There are a number of antenna characteristics which are of primary importance in a microwave system. The first of these is antenna gain. An antenna has gain because it concentrates the radiated power in a narrow beam rather than sending it uniformly in all directions as an isotropic antenna does. Since it reduces the section loss, high antenna gain is obviously desirable. Antenna gain is increased by increasing the antenna area.

Closely associated with antenna gain is beamwidth. Since an antenna achieves gain by concentrating power in a narrow beam, the width of the beam must decrease as the antenna gain is increased.

Practical antennas comprise maximum achievable gain to obtain sidelobe radiation. For reflector type antennas, tapering of the reflecting illumination pattern is used to effect about 55% reflector illumination factor, hence, the actual gain is about 3 dB less than the maximum possible.

Antennas used in microwave systems ordinarily have half power beamwidths of the order of one degree (see figure 12-1). A narrow beam is desirable in order to minimize interference from outside sources and adjacent antennas. Too narrow a beam, however, imposes severe mechanical stability requirements and leads to problems in antenna alignment and signal fading. Not all of the energy from an antenna is in the direction of the main beam; however, some of it is concentrated in minor beams in other directions. These minor beams are called sidelobes and may be important sources of interference into other microwave paths. Figure 12-2 illustrates the relationship between the main beam and sidelobes for a horn reflector antenna.

There are several antenna characteristics which are important in evaluating the interference to be expected between adjacent transmitting and receiving antennas. One such property is the front-to-back ratio. This is defined as the ratio of the power received from (or transmitted to) the front side of the antenna to the power received from (or transmitted to) the back side, for the same incident field intensity, and is usually expressed in dB. Two front-to-back ratios may be given for an antenna. The ideal front-to-back ratio is the ratio that would exist if the antenna were isolated in free space. The effective front-to-back ratio is the ratio that would be measured in a typical antenna installation, and may be 20 dB to 30 dB below the ideal or free space ratio because of reflections from the foreground or from objects in or near the main beam of the antenna. The front-to-back ratios for the antennas described in the next section are effective ratios. One use of the front-to-back ratio in systems analysis is in computing the interfering effect between a transmitting antenna on one tower and a receiving antenna on the preceding tower.



NOTE: ABSCISSA IS ACTUAL ANTENNA AREA AND "ACTUAL ANTENNA GAIN" IS TAKEN TO BE 3 dB BELOW MAXIMUM ACHIEVABLE

$$\frac{A}{\lambda^2}$$

ANTENNA REFLECTOR SIZE	4000 MHz	6000 MHz	11,000 MHz
8–FOOT DIAMETER PARABOLOID	$8(10)^2$	$2(10)^3$	$6(10)^3$
4–FOOT DIAMETER PARABOLOID	$5(10)^2$	$5(10)^2$	$1.5(10)^3$

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Figure 12-1. Approximate Antenna Gain and Beam Width

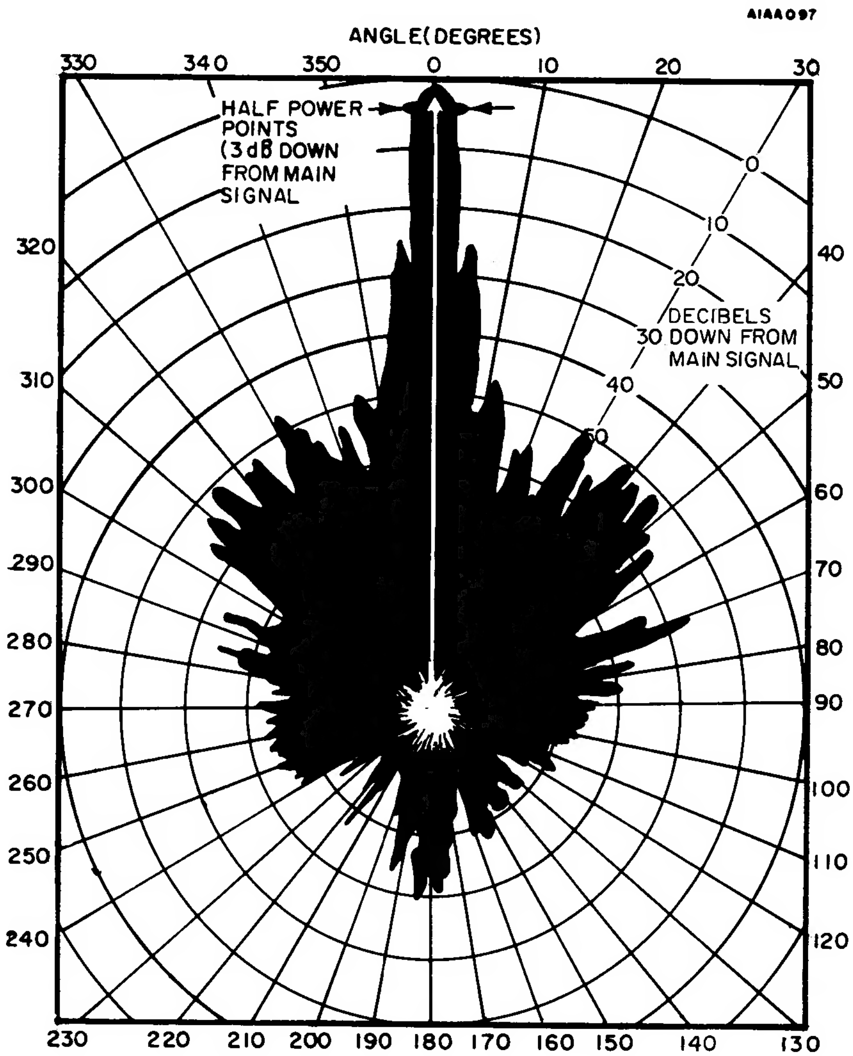

Figure 12-2. Horizontal Directivity of Horn Reflector Antenna at 3740 MHz

Side-to-side coupling expresses the fraction of transmitted power that is received by a second antenna located alongside the transmitting antenna. It is generally expressed in dB. The usual practice is to give the effective, rather than ideal, side-to-side coupling for the particular types of antennas, as measured for specific side-to-side orientations of these antennas.

Back-to-back coupling expresses, in dB, the fraction of the transmitted power received by a second antenna located to the rear of and facing away from the trans-mitting antenna, on the same tower. The value of back-to-back coupling quoted for a pair of antennas is normally the effective coupling as measured in a typical

antenna installation. Both side-to-side and back-to-back couplings are useful in computing the interfering effects between transmitting and receiving antennas located on the same tower.

Some antennas must transmit or receive both vertically and horizontally polarized waves and their cross polarization discrimination is important. As previously defined, the cross polarization discrimination expresses the ratio, generally in dB, of the power in the desired polarization to the power which appears in the opposite polarization due to the residual conversion mechanisms in the antenna system.

Good impedance match must be maintained between the antenna, the waveguide feed, and the radio transmitter in order that reflections do not distort the transmitted signals. The problem of maintaining a good match has been reduced by the use of isolators, which are waveguide devices which pass the signal in the desired direction but effectively block (by absorption) the reflections traveling in the opposite direction.

The cost and complexity of the antenna system are important. The antenna tower and associated antenna mounting arrangements are sometimes an appreciable portion of the cost of a microwave system. When this is true, a balance must be made between the cost saving that can be achieved through the use of a lightweight antenna on a lightweight, inexpensive tower and the improved transmission performance which may result from using a larger and heavier antenna with a correspondingly more rugged and expensive tower. The cost of any antenna system is affected by the difficulty of construction and maintenance.

Consideration must be given to the mechanical tolerances which must be attained in production and maintained in the field under conditions of ice and wind loading. A common rule of thumb for mechanical tolerances on reflecting surfaces is that dimensions should be held within $\lambda/16$. Since at 11 GHz this is 1/16 inch, the construction of large antennas is not simple.

The choice of antenna for any particular system is a result of a careful weighing of the factors noted above to produce the most efficient arrangement within the cost framework dictated by system economics.

12.1 PARABOLIC ANTENNA (PLANE AND DUAL POLARIZED)

The parabolic antenna utilizes a reflector consisting of a paraboloid of revolution and a primary radiator at the focal point. The geometric properties of the parabola enable the reflector to convert the non-directional wave radiating from the focus to a directional coherent wave pattern across the aperture of the paraboloid to concentrate the energy in a beam which is basically the diffraction pattern of the aperature (much like a searchlight beam in the near field).

A plane-polarized antenna uses a single linearly-polarized signal. A dual-polarized antenna is one using two linear polarizations, perpendicular to each other.

Vertical polarization is a linear polarization in which the electric vector is perpendicular to the surface of the earth. Horizontal polarization is a linear polarization in which the electric vector is parallel to the surface of the earth. Normally, microwave systems employ plane-polarized antennas with either vertical or horizontal polarization. In practice, approximately 20 dB isolation may be obtained between signals of opposite polarizations.

12.2 UNIFORM AND TAPERED ILLUMINATION

The antenna 3 dB beamwidth and sidelobe characteristics are intimately related to the dependence of gain on the aperture field distributions. For constant phase distribution across the aperture, maximum gain is realized with uniform illumination. If the illumination over the aperture is modified so that the intensity is peaked in the central area of the aperture and tapered down in magnitude toward the aperture boundary, the diminution in gain is accompanied by an increase in beamwidth and a decrease in sidelobe intensity relative to the peak intensity of the main lobe. The prominence of the sidelobes can be traced to the discontinuity at the edge of the aperture.

12.3 RADOMES

At microwave frequencies the collection of ice or snow can have a deleterious effect on antenna performance. A dish full of soft snow can cause losses of 10 dB at 6 GHz. Worse than this, certain ice formations on the feed can result in high VSWR and considerable attenuation. Radomes are recommended for all antennas by some radio companies, to prevent ice formation in frigid or temperate climates and to reduce the antenna windload on the tower in warmer locations.

The conical fiberglas plastic radomes are attached to the rim of the reflector with steel brackets. Manufacturing methods vary, but stronger, lower loss radomes are fabricated of fiberglas cloth and bonding resins using hand lay-up methods. Lower labor cost radomes can be attained by spray-up manufacturing techniques using a mixture of chopped fiberglas fibers and resin; however, the extra thickness and surface irregularities of this type result in 1.5 to 2 times more attenuation than that of the more expensive hand lay-up radomes.

Higher quality radomes also include a dark gelcoat treatment which seals the surface, extends the life and improves the "slip" factor for shedding ice or snow.

While unheated radomes offer adequate protection in most of the United States, some users prefer heated radomes in areas subject to severe sleet or heavy snow storms. Heated radomes include resistance heating wires molded between the fiberglas layers which are activated by air sensing thermostats in the icing temperature range of 2°C to -4°C. Electronic Industries Association recommends heater powers range from approximately 600 W for a 4-foot radome to 3500 W for a 10-foot radome.

Radome heating wires should be wound in a circular or spiral pattern to eliminate the need for polarization adjustment of the radome during installation and to allow

dual polarized operation if needed. Parallel wire radomes have been known to cause 3 dB or more attenuation if the heater wires are aligned parallel to the electric vector instead of perpendicular to it.

Most standard radomes are designed to withstand winds of 100 mph without damage. For systems subject to hurricane winds or problem locations with extreme wind gusts, special extra strength reinforced fiberglas radomes are available. These radomes will withstand 150 mph winds and introduce about 0.4 dB more attenuation.

Various manufacturers will achieve different attenuation figures, but typical guaranteed radome attenuations are given in Table 12-1. The better performance radomes normally cost more.

Table 12-1. Radome Attenuation Versus Frequency

	DIAMETER (FEET)	2 GHz	6 GHz	8 GHz	12 GHz
Unheated	6	.2 - .4 dB	.5 - 1.0 dB	.7 - 1.2 dB	1.1 - 1.5 dB
	8	.2 - .4 dB	.5 - 1.0 dB	.7 - 1.2 dB	1.2 - 1.5 dB
	10	.3 - .5 dB	.7 - 1.5 dB	.95 - 1.7 dB	1.4 - 2.0 dB
	12	.4 - .5 dB	.8 - 1.5 dB	1.0 - 1.7 dB	1.6 - 2.0 dB
Heated	6	.2 - .4 dB	.5 - .8 dB	.7 - 1.2 dB	1.1 - 1.5 dB
	8	.2 - .5 dB	.5 - 1.0 dB	.7 - 1.2 dB	1.2 - 1.5 dB
	10	.3 - .5 dB	.7 - 1.5 dB	.9 - 1.7 dB	1.4 - 2.0 dB
	12	.4 - .5 dB	.8 - 1.5 dB	1.0 - 1.7 dB	1.6 - 2.0 dB
Most fiberglas radomes have a minor effect on antenna VSWR, ranging from 0.01 to 0.02. In most cases the changes in pattern are negligible, only ±1 or 2 dB.					

Dish and feed heaters have been used on some systems to eliminate the slight losses of radomes. However, the added power required in this age of low drain, solid state equipment and the difficulty of maintenance monitoring have made dish heaters less popular in recent years. Some users have reported that heater failures were not detected until after icing resulted in system outages.

12.4 SHROUDS

High performance antennas offer the high directivity for long haul systems using a two frequency plan for locations in which a better pattern is needed to reduce RF interference. The high directivity is achieved through the use of premium dishes

and feeds, and a cylindrical metal shroud lined with absorbent material to attenuate side and back radiation, as shown in figure 12-3.

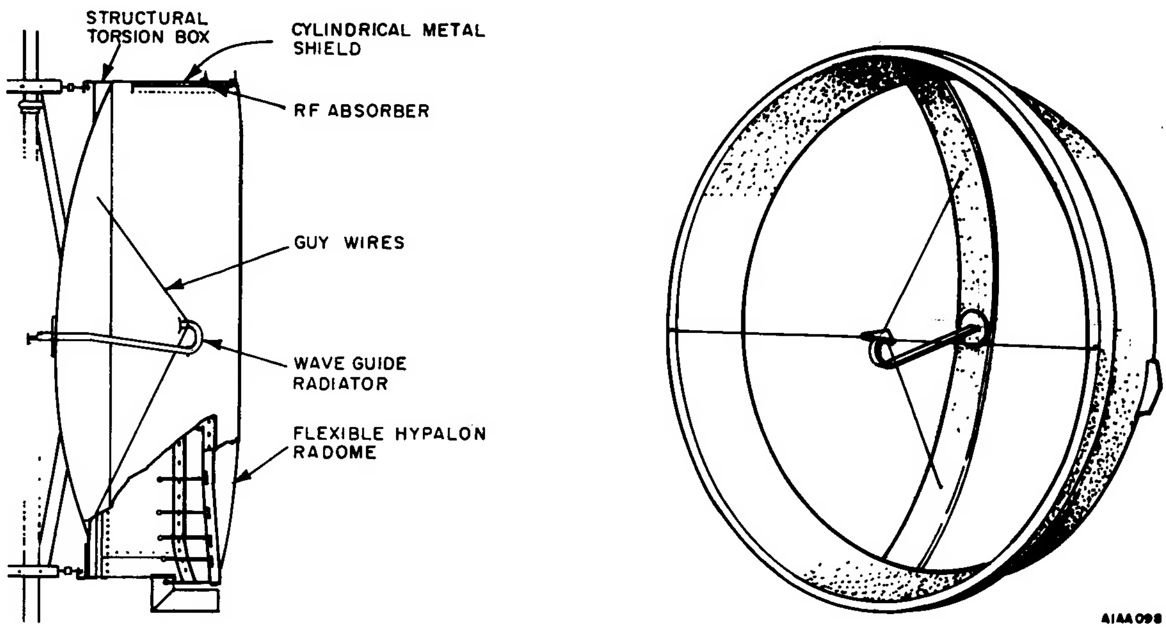

Figure 12-3. High Performance Antenna With Shroud

The antennas use deeper dishes with lower F/d (focal length to diameter) ratios and special low VSWR feeds with absorbent material and illumination shaping aids. Front-to-back ratios (over the region $180^{\circ} \pm 80^{\circ}$) have been achieved in the order of 67 to 72 dB for 8 foot and 10 foot shrouded antennas in the 6 GHz band. High performance antennas also include low pass, planar radomes with 0.1 dB attenuation and negligible VSWR contribution. The long life, Hypalon coated nylon radome is stretched across the opening of the cylindrical shield and spring loaded. The radome surface, under tension, flexes slightly in the wind and readily sheds ice and snow in most U.S. environments.

12.5 HORN REFLECTOR ANTENNAS

In the horn reflector antenna, a vertical mounted horn, located at the focal point, is used to illuminate a section of a parabolic surface which then reflects the energy outwards. Because of the design and size of the horn, the impedance of this antenna is very good, the return loss being between 40 and 50 dB. It is a broadband antenna and can be used with both vertical and horizontal polarization in the

4, 6, and 11 GHz bands. Its nominal characteristics are tabulated in Table 12-2. Due to its shielded construction, the horn reflector antenna has small sidelobes and radiates very little power to the rear, resulting in a nominal 70 dB front-to-back ratio. Measurements made at 6 GHz on a large number of antenna installations have shown that side-to-side and back-to-back coupling, as well as cross-polarization discrimination, of horn reflector antenna systems follow approximately normal distributions. The side-to-side and back-to-back coupling of the antenna system will vary considerably from location to location due to such factors as foreground reflections and leakage of energy at the joints of the waveguide run feeding the antennas. The cross polarization discrimination of the complete antenna waveguide system will be considerably lower than that of the antenna alone. This difference is due primarily to ellipticity of the circular waveguide run feeding the antenna.

Table 12-2. Horn Reflector Antenna Characteristics

FREQUENCY	4 GHz		6 GHz		11 GHz	
POLARIZATION	VERT	HOR	VERT	HOR	VERT	HOR
Midband gain (dB)	39.6	39.4	43.2	43.0	48.0	47.4
Front-to-back radio (dB)	71	77	71	71	78	71
Beam width (azimuth) (degrees)	2.5	1.6	1.5	1.25	1.0	0.8
Beam width (elevation) (degrees)	2.0	2.13	1.25	1.38	0.75	0.88
Sidelobes (dB below main beam)	49	54	49	57	54	61
Cross-polarization discrimination (dB)	50	46	51	51	57	51
Side-to-side coupling (dB)	81	89	120	122	94	112
Back-to-back coupling (dB)	140	122	140	127	139	140
These characteristics are for a particular pair of antennas without any waveguide system attached.						

A disadvantage of the horn reflector antenna is its bulk (large surface area and weight) and difficulty in mounting. Construction is somewhat expensive.

12.6 REFLECTORS (PLANE, CURVED)

Periscope antennas, consisting of tower top 45° screens and ground based dishes, are popular for 6 GHz and 12 GHz systems. VSWR of the periscope configuration itself is negligible and the VSWR depends on the ground paraboloid antenna. The overall gain depends upon the reflector and paraboloid sizes, separation and frequency. A reflector-paraboloid combination will generally give more gain at less cost than competitive tower based paraboloids and long feeders.

Various aluminum passive reflector designs are available from several tower companies. Standard sizes are 6 x 8 feet, 8 x 12 feet, and 10 x 15 feet with rectangular, elliptical, or clipped edge designs. Curved face reflectors are more popular today than the flat face type because the curving results in a slight gain improvement when the curved surface resembles a section of a large parabola with the focal point at the position of the illuminating paraboloid. Gain curves are supplied by microwave equipment suppliers.

A set of typical gain figures are given in Table 12-3.

Table 12-3. Gain for 6.5 GHz Antenna Systems

PARABOLOID ANTENNA	ANTENNA GAIN	*FEEDER LOSS	NET GAIN
8 ft. at 100 ft.	41.9 dB	2.0 dB	39.9 dB
10 ft. at 200 ft.	43.9 dB	3.5 dB	40.4 dB
12 ft. at 300 ft.	45.5 dB	5.0 dB	40.5 dB
*25 ft. added for building to tower run.			

CURVED REFLECTOR ANTENNA SYSTEM	PERISCOPE GAIN	**FEEDER LOSS	NET GAIN
4 ft. dish/8 x 12 ft. reflector, 100 ft.	41.1 dB	0.5 dB	40.6 dB
6 ft. dish/10 x 15 ft. reflector, 200 ft.	43.1 dB	0.5 dB	42.6 dB
8 ft. dish/10 x 15 ft. reflector, 300 ft.	42.8 dB	0.5 dB	42.3 dB
**25 ft. for building to pylon run.			

There are, however, some drawbacks in the relatively high side and back radiation characteristics of periscope antennas. High sidelobe levels sometimes cause false antenna alignment, and a high back radiation (about -45 dB) in the region 20° to 180° precludes the use of a 2 frequency pattern and exposes the system to more potential interference and difficulties in frequency coordination. In addition, the towers must have better stability and the initial alignment may be more difficult for passive reflectors as compared to tower top paraboloid antennas.

12.7 DUPLEXERS

A duplexer is a device which makes possible the use of a single antenna for simultaneous transmission and reception. Where pulse techniques are used and the requirement for simultaneous transmission and reception from the same antenna is not present, electronic switching devices may be used for the transmitter and receiver circuits, respectively. This manner of operation presupposes that the antenna is used for transmitting at one instant of time, whereas it is used for receiving at another instant of time.

A continuous wave (CW) system imposes more restrictive conditions on the duplexer than would a system involving pulse transmission. Where CW is used, a duplexer must effectively keep the transmitter disconnected from the receiver at all times and yet maintain maximum coupling between the transmitting and receiving antenna circuits. If the transmitted and received signals are on the same frequency and polarization, it can be shown that a lossless 3 terminal network cannot satisfy these requirements. A 4 terminal network, however, can satisfy these requirements, such a network being in nature of a magic T. However, the use of this device requires that the fourth terminal, the one not connected either to the transmitter, receiver, or antenna, be terminated in a matched load. This matched load dissipates both 1/2 of the transmitted power and 1/2 of the received power indicating that if the device is essentially lossless, then there is still an insertion loss of 3 dB whether the transmitted direction or the received direction be considered. Not only is this loss undesirable from the aspect of circuit efficiency, but this loss imposes severe requirements on a terminating load, especially where high powered transmitters are being used.

To avoid these restrictions, the transmitted signal and the received signal are usually separated in frequency and the frequency difference between these two signals makes possible their isolation one from the other while maintaining a good coupling factor to the antenna. Essentially, the device is so tuned that the receiver leg appears to have an admittance (electrical impedance) approaching zero at transmitting frequency, whereas the transmitter leg has an admittance approaching zero at the receiving frequency. The antenna must be sufficiently broadbanded so that both the transmitted frequency and the received frequency can be matched with a low VSWR.

Figure 12-4 illustrates the principle of operation of such a duplexer. The transmitter and receiver legs are connected in parallel to the antenna. The bandpass filter on the receiver leg is so constructed that it presents the characteristic admittance of the line at the center frequency of the received signal, yet presents an admittance

approaching zero at the transmitted frequency. The bandpass filter in the transmitter leg is similarly constructed; the junction exhibits the characteristic admittance of the line at the center frequency of the transmitted signal, yet presents an admittance of essentially zero at the received frequency. Practically speaking, the receiver leg does not exist as far as the transmitter frequency is concerned, nor does the transmitter leg exist as far as the received frequency is concerned. Figure 12-4 illustrates the parallel combination; series coupling is also possible, but is not commonly used.

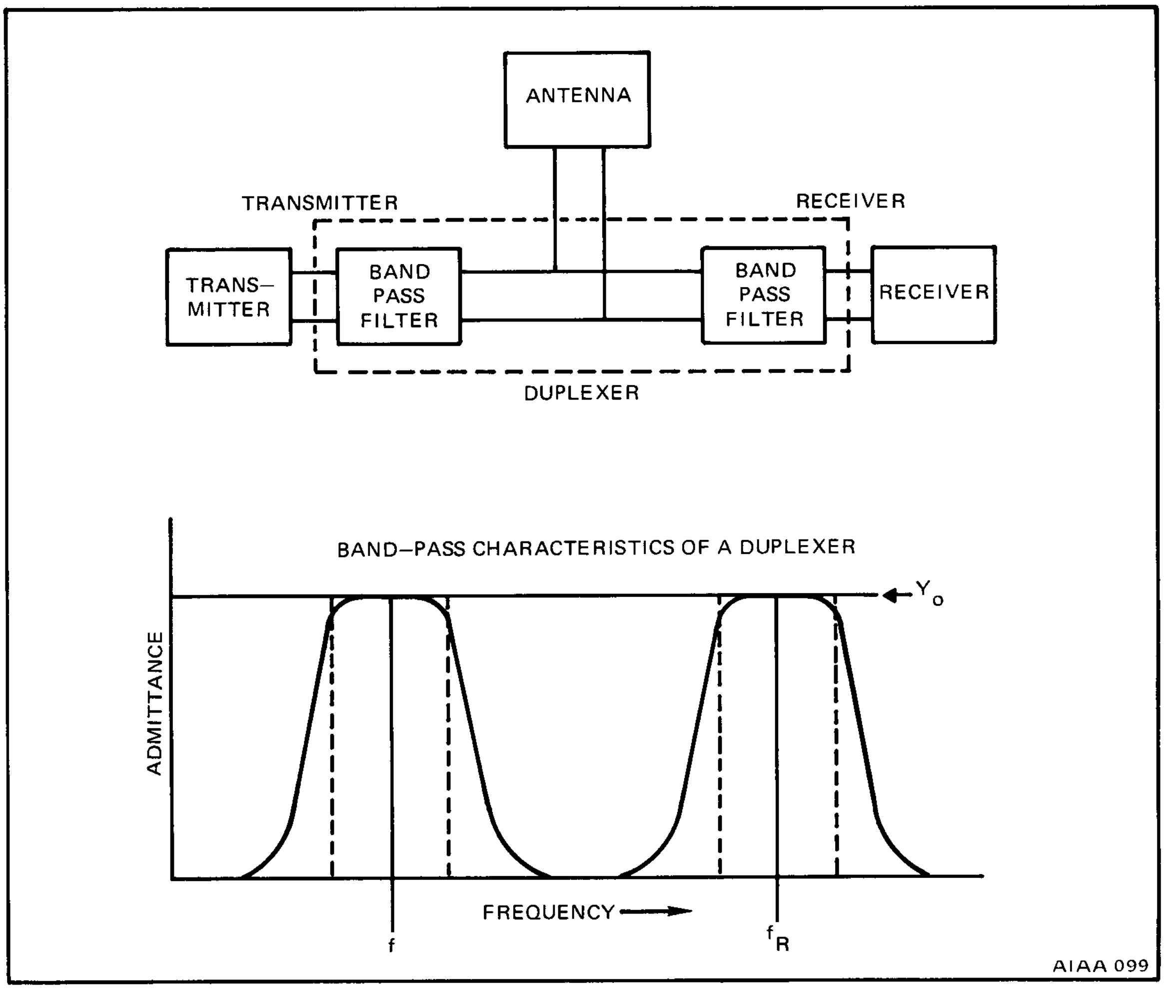

Figure 12-4. Operation of a Duplexer

Isolation between the transmitter and receiver is directly related to the quality of the bandpass filter used in each leg. From the standpoint of admittance matching, the object of the design is to keep the susceptance of the off-resonant branch as small as possible with the conductance essentially zero. With respect to the resonant frequency of each branch, the insertion loss should be kept at a minimum over a wide band, while the attenuation of the resonant frequency of the opposite leg should be maintained at a maximum. The bandpass filters are required to have a fairly flat top and very good selectivity; i.e., sharp skirts to the response curve as shown in figure 12-4.

The duplexer is essentially two bandpass filters terminated in the transmitter and receiver, respectively, and connected to the antenna in parallel. The coupling between the transmitter leg and the receiver leg is a function of the characteristic of the bandpass filters and the separation in frequency between the transmitter leg and the receiver leg.

This type of duplexing can be extended to include almost any arbitrary number of transmitters and receivers operating in this fashion, with each addition to the junction being characterized by its own particular bandpass filter. The method is exactly the same, with the exception that the antenna must be capable of increasingly broad-banded operation as the number of inputs increase. Where many of these inputs are required, a simple junction as illustrated in figure 12-4 will not suffice and these inputs usually are distributed along a transmission line. This requires more complicated matching since the sections of transmission line between the inputs can be critical where length is concerned with respect to the operating frequency of each input. Line stretchers can be used between inputs of this nature to tune the overall complex for optimum operation over the frequency ranges desired.

The following paragraphs concentrate on the simple duplexer; i.e., a single transmitter and a single receiver coupled to the antenna. Usually the duplexer is not field tunable and in manufacturing it is fixed-tuned to operate over the required frequency band; therefore, it is unnecessary to consider the different methods used to achieve this goal.

A duplexer can be made in different ways. Probably the most common uses coaxial transmission line for the bandpass filters. For simplicity of design, a duplexer using waveguide is advantageous since the filter can be built into the waveguide by means of irises. Irrespective of the type, the principles are exactly the same; what is considered with respect to waveguide duplexers applies equally well to coaxial duplexers. In measuring the characteristics of such a duplexer, it can be considered to be a 3-port black box with an antenna terminal, a receiver terminal, and a transmitter terminal. Important parameters to be considered when measuring a duplexer for satisfactory operation are:

- o Coupling factor between the antenna and receiver.
- o Coupling factor between the antenna and transmitter.

- o Attenuation in the receiver arm of the transmitter frequency.
- o Attentuation in the transmitter arm of the receiver frequency.
- o Bandpass characteristics of each arm centered on its own proper resonant frequency.

Even at relatively low frequencies, such as 300-500 MHz, waveguides have been used in the section for the duplexer. This utilizes the simpler construction techniques for incorporating the bandpass filters in the duplexer proper.

12.7.1 Insertion Loss or Coupling Factor of the Duplexer

Measurement of the coupling factor between the antenna and the transmitter and receiver ports, respectively, is a measure of insertion loss (attenuation factor) of the duplexer. A method for measuring insertion loss (coupling factor) must allow for any inherent directive qualities which the duplexer may have. Such a method consists of monitoring a signal fed from the antenna into the duplexer and monitoring the signal at the receiver port.

Conversely, a signal can be injected into the duplexer at the transmitter port and monitored at the antenna port. The difference between the input and output signals is a measure of duplexer insertion loss. A receiver whose power level can be monitored is used as a detector on the receiving leg, and a signal generator tuned to the receiving circuit center frequency is connected to the antenna terminal. A signal at the center frequency of the receiving system whose level is accurately monitored at the signal generator is fed through the antenna port and received at the receiving port, and the signal level is recorded at the receiver. If an output meter is not available at the receiver, provision can be made to measure the AGC voltage which can be used as the level determining reading. The signal generator is then connected directly to the receiver (the circuit remaining the same except that the duplexer has been removed from it). Again the same monitored signal is received at the receiver, and its level noted. The difference between the two levels would be the duplexer insertion loss. The same method would be used on the other duplexer leg with the signal generator connected to the transmitter port and the receiver connected to the antenna port. If an insertion loss greater than 1/2 dB is noted, the duplexer may not be in proper operating condition. (Since the duplexer is not adjustable, excessive insertion loss could indicate that the duplexer was not well designed. Remember that for this measurement the port which is not being measured must be terminated in the characteristic impedance of the line.)

12.7.2 Bandpass Characteristics of the Duplexer

The method of measuring duplexer insertion loss may be extended to measure the duplexer bandpass characteristics if a variable frequency receiver in the range of operation is available. Since the usual 1/2 dB bandwidth of the duplexer should

be known, a number of points within the region of the center frequency should be sufficient to determine the flatness of the curve over its desired bandwidth. The signal generator could be tuned to several discrete frequencies and the receiver tuned to meet these frequencies. A comparison of the receiver output is then graphed to determine the bandwidth characteristics of the duplexer. It is recommended that these measurements include frequencies other than those contained within the 1/2 dB bandwidth. The nature of the selectivity of the filter can be well estimated if the 20 dB bandwidth is measured. This would entail measuring several additional points where the receiver response is down to as great as 20 dB below the response at the center frequency.

12.7.3 Isolation of the Duplexer

Since the attenuation necessary between the transmitter and receiver leg is extremely high (in excess of 100 dB), ordinary methods of measuring this isolation will not be adequate. Duplexer performance can best be determined while it is in use in the actual circuit. The necessity for a good degree of isolation can be illustrated by referring to figure 12-5. The response curve to the left is the idealized frequency response curve of the transmitter leg. The response curve to the right is the idealized receiving leg frequency response curve. It can be seen that the response of the receiver leg to the transmitter frequency should be maintained at a minimum. Response of the receiver leg to transmitted energy is illustrated by the shaded portion in the transmitter bandpass. The amount of area under this curve is indicative of the amount of energy from the transmitter that appears in the receiver leg. The isolation of the receiver leg from the transmitter leg is indicated by the distance A, the attenuation from the peak power of the transmitter. This attenuation should be maximum. Two effects will follow if attenuation A is not sufficient:

- Increased noise will appear in the bandpass of the receiver.

- If the energy associated with this unwanted signal in the receiver leg is sufficiently high, it can block the receiver RF stages. This situation is idealized in that it assumes that all the energy from the transmitter will be contained within the indicated bandwidth which, of course, is not necessarily true.

The method utilized in the following paragraphs constitutes an approximate determination of the change in noise level and in minimum detectable signal caused by the use of the duplexer.

The receiver will be connected to the receiver port, the transmitter to the transmitter port and the antenna to the antenna port. With the transmitter off, a recording of the noise output of the receiver should be determined; i.e., after the initial warmup time has elapsed, the receiver should be allowed to operate merely on the noise from the system. Then the transmitter should be turned on and should be adjusted to maximum operating power with full modulation. The noise level of the receiver should again be recorded for comparison with the first recording. If no discernible difference (less than 1 dB) is evident between the two recordings, it can be assumed that the isolation between the transmitter and the receiver is sufficient.

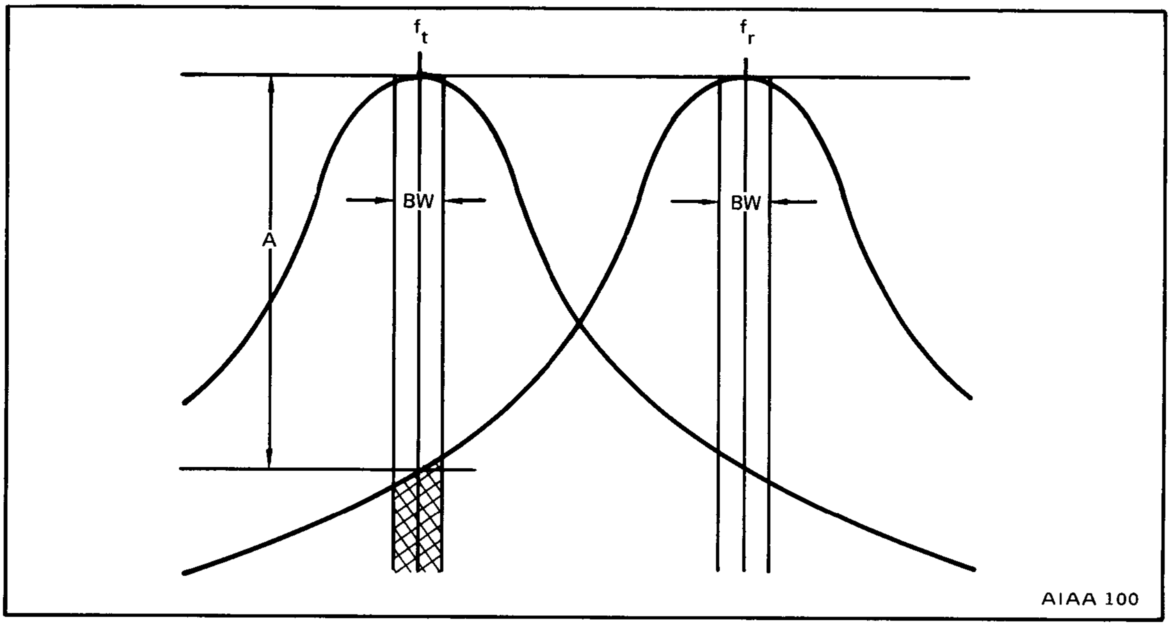

Figure 12-5. Relative Pass Bands of the Transmitter and Receiver Bands of a Duplexer

Receiver blockage due to excessive energy from the transmitter will be very apparent in that the receiver will tend to saturate, causing the receiver noise level to change markedly, indicating the duplexer to be inadequate.

Measurement of the receiver output should be made immediately after the IF amplifier or immediately after the detector. The degree of isolation is not only a function of the duplexer, but is also a function of the selectivity of the receiver.

If significant difference is noticed between the two recordings of the noise level of the receiver, it should be determined if this increased noise in the receiver on the second reading is due to the lack of isolation of the duplexer or due to the leakage or radiation of the transmitter. The following method may be used to determine the extent of isolation. The receiver is disconnected from the duplexer and both the receiver and the duplexer are terminated in good quality, matched terminations with the matched load. A record of the noise level is obtained. The transmitter is then turned on and adjusted to full power and full modulation. A second record of the noise level of the receiver is obtained. If there is any difference between these two readings; i.e., greater than 1 dB, it can be assumed that stray coupling between the transmitter and the receiver is excessive and the determination of the performance of the duplexer would be in error. It is extremely important, for the accuracy of this determination, that grounds be maintained between the duplexer and the transmission line to the receiver so that the paths of stray coupling experienced while

the duplexer was in the system will not be disturbed. If excessive coupling is noted between the transmitter and receiver when they are not connected through the duplexer, steps must be taken to eliminate the stray coupling problem before the duplexer can be measured. If the increase in the noise level due to operation through the duplexer is in excess of 1 dB, the isolation should be considered inadequate.

12.7.4 Circulators

A waveguide circulator is used to couple two or three microwave equipments to a single antenna. Such an arrangement is useful when diversity equipment is employed or when additional microwave equipment is added to existing equipment to increase channel capacity. The particular type of waveguide circulator described here is a ferrite device which is similar in design to duplexers used in other microwave applications. The circulator (figure 12-6) consists of three basic waveguide sections combined into a single assembly. The end section that terminates in arms 1 and 3, is a modified magic T. The other two arms of the modified magic T are folded so that they are parallel and feed into the center section of the circulator. The center section is a ferrite non-reciprocal phase shifter. It consists of two parallel lengths of waveguide each containing a strip of ferrite material. An external permanent magnet causes the ferrite material to exhibit phase shifting characteristics. The third section of the circulator is a short slot hybrid which has a coupling slot in the common wall of the parallel lengths of waveguide.

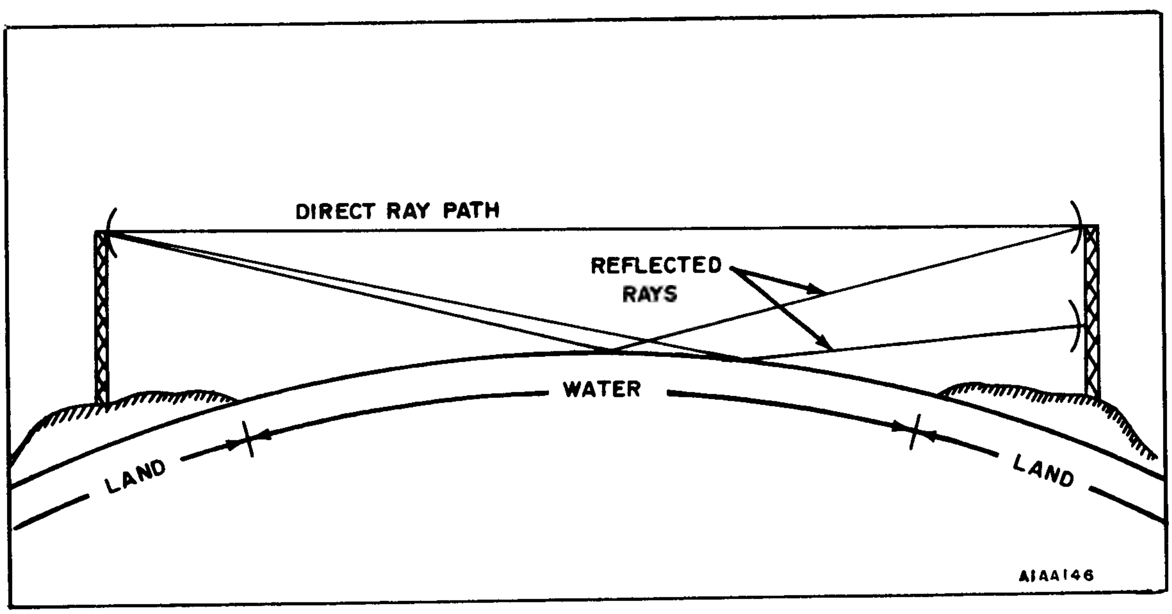

Figure 12-6. Waveguide Circulator

With an antenna connected to one arm and either three microwave equipments connected to the other arms or two equipments and a shorting plate connected to the other arms, the following rules apply: The attenuation from arms 1 to 2, 2 to 3, 3 to 4, and 4 to 1 is about 0.5 dB in each instance. Attenuation between other combinations of arms is considerably higher, on the order of 20 dB. For example, the attenuation between arms 1 and 3 is high because of the properties of the short-slot hybrid. Finally, the attenuation from arms 1 to 4, 4 to 3, 3 to 2, and 2 to 1 is high because of phase cancellation brought about by the combined effects of all three sections.

Assuming that the antenna is connected to arm 4, the net attenuation (approximately) of the circulator on transmission and reception is shown in Table 12-4. By using identical arrangements of circulators and transmitter-receivers at two or more stations, the circulator losses can be equalized for each parallel path. This is shown in the table since the transmission loss at one station plus the reception loss at the next station can be made to total approximately 2 dB for each of the three sets of equipment.

Table 12-4. Circulator Attenuation

	TRANSMISSION LOSS (dB)	RECEPTION LOSS (dB)	TOTAL T-R LOSS (dB)
Transmitter-Receiver No. 1 Connected to Arm 1	1.5	0.5	2.0
Transmitter-Receiver No. 2 Connected to Arm 2	1.0	1.0	2.0
Transmitter-Receiver No. 3 Connected to Arm 3	0.5	1.5	2.0

12.8 WAVEGUIDE

Waveguide and transmission line is important not only for its loss characteristics, which enter into the path loss calculation, but also for the degree of impedance matching attainable, because of the effect on echo distortion noise. The latter becomes extremely important with high-density systems having long waveguide runs.

In the 2 GHz bands coaxial cable is usually used, and, except for very short runs, it is usually of the air dielectric type. Typical sizes are 7/8 inch, with an attenuation of about 2 dB per 100 feet and 1-5/8 inch, at about 1.1 dB per 100 feet. It is

normally ordered in the exact lengths required, with factory installed and sealed terminal connectors. When larger size cable is used, it is desirable to reduce to 7/8 inch with a suitable transition, for flexibility in connecting to the radio equipment. In some cases, similar treatment may be needed at the antenna end, though generally the use of a rigid right angle connector will allow sufficient flexibility for antenna orientation.

The other bands use waveguide almost exclusively, one of three basic types; rigid rectangular, rigid circular, and semiflexible elliptical. The elliptical type is of continuous construction, while the other types come in sections with flanges. Short sections of flexible waveguide are also used for the connections to the antennas and to the equipment. In all cases it is desirable to keep the number and length of flexible sections as small as possible, since they tend to have higher losses and poorer VSWR than the main waveguide types. (See figure 12-7.)

12.8.1 Rectangular Guide

Rigid rectangular waveguide is the most commonly used, with oxygen free, high conductivity copper (OFHC the recommended material. The types and approximate characteristics are as follows:

- 4 GHz bands. WR 229, standard for most installations, has a loss of about 0.85 dB/100 feet.

- 6 GHz bands. WR 137 (normally used) has a loss of about 2.0 dB/100 feet. In cases where, due to high towers, a reduced transmission loss is required, transitions can be supplied for use with WR159, which has a loss of about 1.4 dB/100 feet.

- 7-8 GHz bands. WR 112 is normally used. Attenuation is about 2.7 dB/100 feet.

- 11 GHz bands. WR 90 is normally used. Attenuation is about 3.5 dB/100 feet.

- 12-13 GHz bands. WR 75 is normally used. Attenuation is about 4.5 dB/100 feet.

For critical applications, where extremely low VSWR is required to meet stringent noise performance specifications, special precision waveguide, manufactured to a very tight tolerance, is recommended.

12.8.2 Circular Guide

Circular waveguide has the lowest loss of all, and in addition, it can support two orthogonal polarizations within the single guide. It is also capable of carrying more than one frequency band in the same guide. For example, WC281 circular guide is

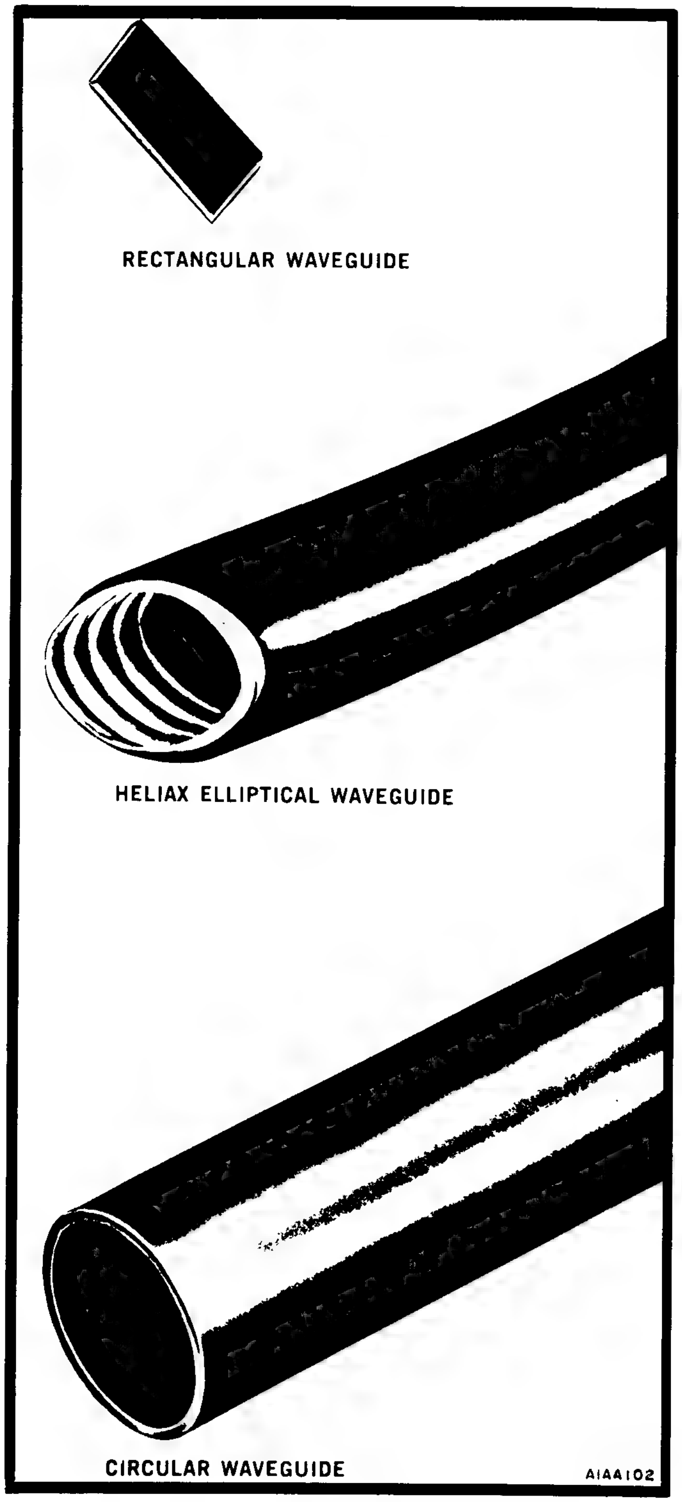

Figure 12-7. Types of Waveguide

normally used with horn reflector antennas to provide two polarizations at 4 GHz and two polarizations at 6 GHz. But circular guide has certain disadvantages. It is practical only for straight runs, requires rather complicated and extremely critical networks to make the transition from rectangular to circular, and can have significant moding problems, when the guide is large enough to support more than one mode for the frequency range in use. Consequently, though circular waveguide is available in several different sizes, and its low losses make it attractive, it is recommended that it be used with considerable caution.

12.8.3 Elliptical Guide

Semiflexible elliptical waveguide is available in sizes comparable to most standard rectangular guides, with attenuations differing very little from the rectangular equivalents. The distinctive feature of elliptical guide is that it can be provided and installed as a single continuous run, with no intermediate flanges. When very carefully transported and installed, it can provide good VSWR performance, but relatively small deformations can introduce enough impedance mismatch to produce severe echo distortion noise.

The most commonly used types and their approximate characteristics are as follows:

- 4 GHz band. EW-37, about 0.85 dB/100 feet.
- 6 GHz band. EW-59, about 1.75 dB/100 feet.
- 7-8 GHz bands. EW-71, about 2.5 dB/100 feet
- 11 GHz band. EW-107, about 3.7 dB/100 feet.
- 12-13 GHz bands. EW-122, about 4.5 dB/100 feet.

In all types of waveguide systems it is desirable to keep the number of bends, twists, and flexible sections to a minimum. It is also vitally important to use great care in installation, since even very slight misalignments, dents, or introduction of foreign material into the guides can create severe discontinuities.

12.9 DEHYDRATORS AND PRESSURIZERS

Variation in temperature and humidity can cause condensation on the inside of a waveguide run or air dielectric cable if they are not pressurized. This condensation will seriously impair line electrical efficiency and, in the case where a section or line is filled with water, complete system failure can result.

12.9.1 Static Pressure System

The static system is one in which the transmission lines are pressurized by means of a dry air pump, a dehydrator or a nitrogen tank. After the desired pressure is reached, the system is sealed off by means of a valve, and the pressurization source is removed.

In a static system, the cable gauge pressure will vary with temperature and barometric pressure changes in accordance with the physical law governing the behavior or perfect gases. Therefore, system pressures must be adequate to accommodate the most extreme conditions.

Barometric pressure changes usually do not cause detectable changes in system pressures and they can be omitted from consideration for most situations.

Temperature differentials are more severe and can cause significant changes. Temperature change of 80°F can lower internal system pressures 1 to 2 PSIG. An exact system pressure cannot be stated since environmental conditions vary; however, a system pressure of 3 PSIG is necessary for most conditions.

12.9.2 Dynamic Pressure System

A dynamic system is one that incorporates a pressurizing source which acts as a system reservoir. The pressurizing source, automatic dehydrator or nitrogen gas cylinder, remains in the system and maintains positive pressure in the line at all times.

A dynamic system may be accomplished with an automatic dehydrator or a nitrogen gas cylinder. Either medium can be connected into the system so that it maintains a pressure greater than atmospheric (3 PSIG is recommended) in the transmission line. It should be noted that for a dynamic system the pressure need only be nominally positive; higher pressures offer no advantage and increase the loss of pressurizing medium, since leakage rates increase rapidly with increases in internal pressure.

Dry air and nitrogen are very similar and either gas is satisfactory for pressurizing transmission lines. Nitrogen cylinders are recommended for use in simple installations. Automatic dehydrators are recommended for extensive waveguide runs and more complex installations.

12.10 DIVERSITY COMBINERS (PRE-DETECTION, POST-DETECTION)

The value of diversity systems is realized only if the opertions at the receiving site are such that the signal available at the output of the system is a better reproduction of the original modulating signal than that obtainable from using a single copy of the signal. So the problem becomes a question of how to utilize the available disturbed copies of the signal in order to achieve the least possible loss of signal information. The techniques available fall into three general classifications. These are: switching, combining, and a combination of the two; and may be accomplished on the noisy, fading carriers (pre-detection), or on the noisy, fading modulation components after extraction from the carrier (post-detection).

12.10.1 Switching Technique

In the switching technique, each of the signal copies available is scanned, compared to each of the others, and the one selected becomes the only signal effective in the following stages. In one such system, the waveforms of the available signals are scanned in sequence, and the first one in which the quality exceeds a predetermined threshold is switched in and is held in until its quality falls below the threshold, when the scanning process is repeated. In this system, the output signal is not necessarily the best, but will be above the threshold of acceptability. In another system, all available signals are scanned simultaneously and the one having the best quality is selected. These are known as the scanning-diversity and optimal-selection diversity techniques. In high frequency space-diversity systems, the several antennas feed several receivers that go to a common output. The receiver which has the strongest signal develops the AVC voltage which controls the gain of all the receivers, which gives, in effect, a switched system on an optimal selection basis.

12.10.2 Combining Techniques (Equal Gain, Maximal Ratio)

In the combining techniques, all of the available waveforms are utilized simultaneously. Of all the possible choices of combining signals, two are of most interest. First, if we assume no prior knowledge that any given copy will always be poorer than the others, all are weighted equally in the total signal summation, regardless of the quality fluctuations that will be experienced. Thus, equal mean values of signal level and equal rms values of noise being assumed, the combination is made and is known as equal-weight or equal-gain combining. Second, since the output of any of the channels is a function of the signal quality in the channel, each output is constantly adjusted to give the best signal-to-noise ratio before combining with other channels. This is called maximal-ratio combining. In the alternate switching and combining method, some of the signals are dropped when they become appreciably noisier than the others, with the remaining signals being combined to obtain the maximum possible signal-to-noise ratio in the output signal.

Figure 12-8 shows the improvement which may be expected in the average signal-to-noise ratio at the output of a diversity receiving system over that of a single channel system. The three methods of selection or combining previously discussed are shown in their relative effectiveness as the number of diversity channels is increased. Figure 12-9 is a percent-of-time plot of a two channel diversity system, with the same three methods of utilization, compared to a single channel system when random fading of the signal occurs.

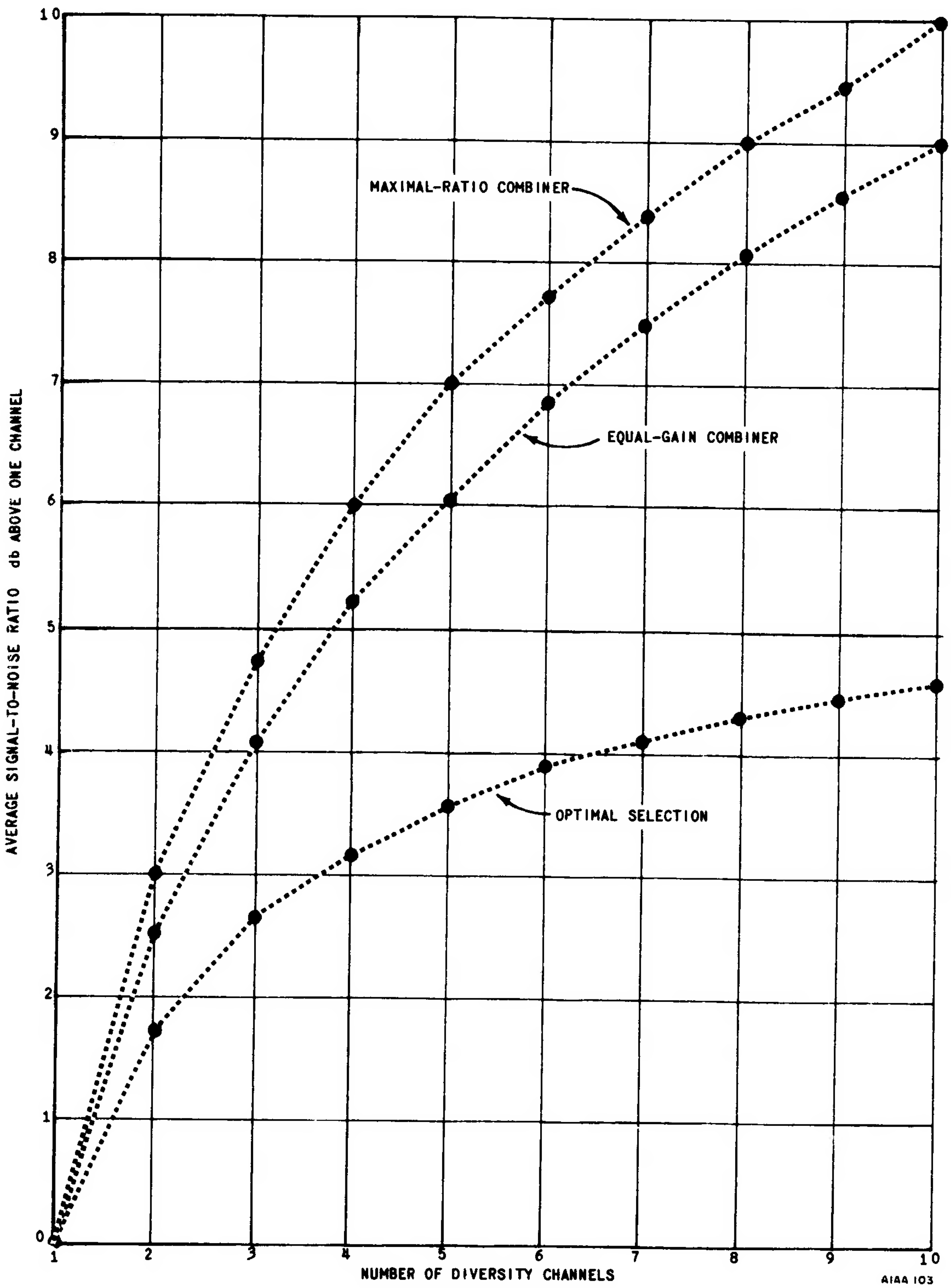

Figure 12-8. Improvement in Average Received Signal-to-Noise Ratio With Diversity

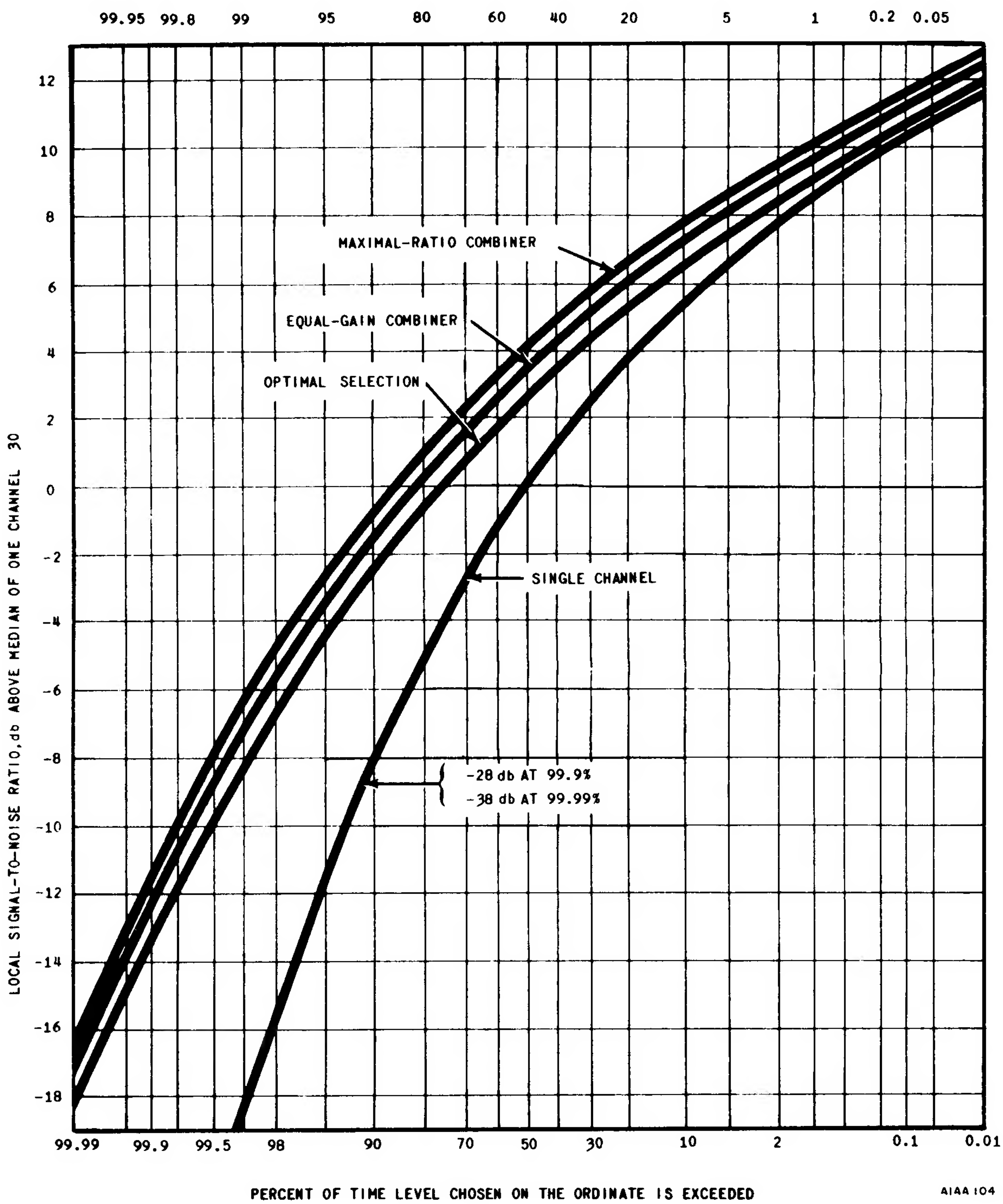

Figure 12-9. Percent-of-Time Distribution of Received Signal-to-Noise Power Ratio for Single Channel and Two-Channel Diversity Using Three Combining Methods